Physics 364 – fall 2010

Lab #1 – resistors, voltage dividers, input/output resistance, lab equipment, and other basics

Meeting time: Monday, September 13, 5-9pm, ~~RCA~~ Detkin Lab, 1st floor Moore Hall.

We (Bill and Jose) will hand out breadboards and toolkits for you to use throughout the semester. You should take your own set of supplies to label with your name, in case you want to save your work between labs in the future. You can work either alone or with a partner, as you prefer. If you work with a partner, you can work either at one lab station or at two adjacent stations. Your write-up must be your own, and should who your lab partner is, if any.

The purpose of the lab report is twofold.

First, your report gives you credit for working through all of the lab exercises – as this process (interacting with the components, the instruments, the instructors, and your classmates) is the primary way in which you will learn electronics this semester.

Second, you will develop the habit of keeping a running log of what you are doing in the lab. Keeping a notebook is an important part of doing original research, and can be helpful even if you are just sitting at home debugging the new video game you wrote last weekend or are in your parents' garage doing a difficult car repair. By explaining what you are doing and why to someone else (who usually turns out to be yourself long after you've forgotten the details of today's work), you clarify your reasoning and can work more systematically. And you will be surprised how often your old notebooks will contain valuable clues for reproducing today's work when you unexpectedly need to revisit them in a year's time.

We will try to provide some examples of acceptable lab notebooks. The basic idea is to explain what you are doing in the lab with enough detail that if you pick it up six months from now, it will be clear what you did and why you were doing it. That's all. Nothing elaborate is needed. (For another take on lab notebooks, see http://en.wikipedia.org/wiki/Lab_notebook .) While lab notebooks have traditionally been bound paper volumes, electronic documents have become popular, as they are easy to find, to search, and to share, and they avoid the hassle of carrying around a physical notebook. A "google docs" word processor document worked well for me (Bill) for several years. More recently, I have started using a wiki to document my own lab work. You can use a spiral notebook, a word processor, a wiki, or any similar means, as long as your notebook is readable, is reasonably neat, and adequately documents your lab work. I will bring a scanner to lab sessions so that you can draw graphs and circuit diagrams by hand and paste them into your notebook, if you choose the electronic route.

If you bring your own notebook computer into the lab, I will guide you through installing LTspice – a free circuit simulation program from Linear Technology – on your computer. If your computer is a Mac, the installation will be much easier if you are already running a virtual Windows machine via VMware, Parallels, VirtualBox, etc. I have managed to install LTspice on my own Windows, Linux, and (Intel) Mac OS X computers, but it installs most simply under Windows.

Part 1: using the multimeter

Pick out a range of resistors from the parts drawers. Choose about 5 different values, sampling the range from a few ohms to a few hundred kΩ. Measure each resistance with the multimeter (HP 34401A – user manual can be found with google). Check the reading against the color codes on each resistor. (It's worth memorizing black, brown, R, O, Y, G, B, V, grey, white.)

Starting with the larger resistors and working your way down, measure I vs. V for a few points per resistor. Use the power supply to program the voltage across the resistor-plus-meter, and use the multimeter to measure the current through the circuit. Before applying each voltage, keep in mind the 0.5 watt resistor power rating, and choose settings that won't cook the resistor! As you work your way down to smaller resistances, at what point do your results begin to surprise you? At what point do you need to start to consider the internal resistance ("shunt resistance") of the ammeter? What is the specified resistance (chapter 8 of HP34401 user guide) of the meter when measuring small currents?

Do the surprising values make more sense when you consider the meter's own resistance? For the small/surprising resistors, use a second multimeter (hand-held, or using long leads to extend the next-door station's meter) measure the voltage across the two leads of the resistor.

Part 2: voltage divider

Build a voltage divider from one 1kΩ and one 2kΩ resistor (or slightly different values if supplies are low), such that the output voltage is about 2/3 of the input voltage. Draw your circuit's schematic diagram. Supply 3 volts to the divider's input. Measure Vout.

Measure Vth and Rth (Thevenin equivalent) for the divider, between Vout and ground. How did you measure them? How do they compare with what you calculate by looking at the schematic?

Now load the divider with a 100K resistor. Draw the new schematic. Measure Vout. Does it make sense?

Now load the divider instead with a 3K resistor, and measure Vout. Does the result make sense?

Now draw, and then build, the Thevenin equivalent circuit for your voltage divider. Try loading the equivalent circuit with 100K, then with 3K. In what sense is the Thevenin equivalent circuit equivalent to the original circuit?

Build a new voltage divider using two 1.6MΩ resistors. Apply 16V as to the input. Measure the current through the divider. How did you do it? Is the answer what you expect? Now use the HP multimeter to measure Vout. Whoa! What do you read? Look up the HP34401 meter's input resistance. Draw the circuit that includes the meter's input resistance. Does the reading make sense now?

Part 3: voltage divider as load for voltage divider

Re-build the original 1K:2K voltage divider from part 2. Now build a second voltage divider using much larger resistors, e.g. 100K:200K. Use Vout1 from the first divider to supply Vin2 for the second divider. Draw the circuit. What is the "input resistance" of the second divider? What do you expect for Vout1 and Vout2? Measure them?

Now replace the 100K:200K divider with a second 1K:2K divider. You should have two identical voltage dividers, with Vout from the first feeding Vin for the second. What is the input resistance of the second divider? Now what do you expect for Vout1 and Vout2? Measure them.

A rule of thumb for voltage sources (opposite for current sources) is that the "source resistance" (i.e. Vth) of the driving circuit needs to be much smaller than the "input resistance" of the load, if you do not want the source voltage to "droop" or "sag" under the load. The advantage of following this rule of thumb is that it allows you to consider the parts of a complicated circuit individually. Alternatively, keeping in mind Rth for the driving circuit and Rin for the load allows you quickly to calculate or to approximate the interactions between two adjacent stages of a circuit. Does this exercise make the rule of thumb clear to you?

Part 4: mystery boxes

Measure I vs. V for each of the two mystery boxes at the front of the room. You can safely apply up to 10V to each box. How did you make your measurements? Which one of the boxes seems a bit unusual? Once you're done, you can look inside.

Part 5: scope, function generator

Put your venerable 1K:2K voltage divider back together. Drive it with a 1 kHz, 2Vpp sine wave from the function generator. Connect the oscilloscope to graph Vin and Vout vs. time. Does the voltage divider behave as you expect for time-varying input?

Now replace the 2K resistor with a 1N4148 (or similar) diode. Sketch Vin(t) and Vout(t). You should see the diode *clamp* Vin at about 0.7 volts. This feature is often used to protect sensitive circuits from excessive input voltage.

Try using XY mode of the scope, so that you can graph Vout vs. Vin. To simplify the interpretation, swap the inputs so that you are instead graphing Vin vs. Vout, strange as it may sound. Sketch the XY graph.

Measure I vs. V (current through the diode vs. voltage across the diode) for the diode at a several voltages. If you don't have a second meter, use the known value of the resistor and the measured current to infer the voltage across the diode. Collect enough points near V=0.7 volts to see the diode turn on.

Now look again at your XY graph. The scope is graphing Vin vs. Vdiode. (Ideally, one would graph Vin-Vdiode vs. Vdiode to trace out R·I vs. V for the diode, but the ground-referenced scope inputs make that difficult.) Vin = Vdiode + I·R. Before the diode turns on, I≈0, so Vin = Vdiode – a line with unit slope. Once the diode turns on, the exponential I(Vdiode)·R is added to the unit-slope line. Not too profound, but you've found an excuse to learn to use the scope's XY mode.

If you're not yet out of time, spend a moment tinkering with the function generator and oscilloscope, to get to know their features. Ask Bill, Jose, and your classmates about anything that you find interesting or puzzling. For the rest of the course, the oscilloscope will be your means of seeing what is happening inside your circuits. Work with it until you are comfortable.